Marine Boundary-Layer and Air-Sea Interaction

Djamal Khelif
Departments of Mechanical and Aerospace Engineering
University of California, Irvine
Irvine, CA 92697-3975
phone: (949) 824-7437 fax: (949) 824-8585 email: dkhelif@uci.edu

Award #: N000140310305
http://wave.eng.uci.edu

LONG-TERM GOALS

The long-terms goals of the research are to understand and parameterize the physics of air-sea interaction and the marine boundary layer over a wide spectrum of weather and ocean conditions.

OBJECTIVES

The main objectives of this effort are to study the air-sea interaction under different conditions: cold air outbreaks in the Japan/East Sea experiment, trade winds off the east coast of Oahu, Hawaii during the Rough Evaporation Duct experiment (RED), stratocumulus marine layer off the central coast of California during the Cloud-Aerosol Research in the Marine Atmosphere I,II & III (CARMA I, CARMA II & CARMA III) and the summertime mostly stable boundary-layer south of Martha's Vineyard, Massachusetts during the Coupled Boundary Layers/Air-Sea Transfer (CBLAST – Low winds)

We are primarily interested in the characterization of boundary-layer structure, the measurement of momentum, heat and water vapor (latent heat) air-sea fluxes, the determination of their spatial variability as well as their parameterization.

APPROACH

The Navy NPS CIRPAS Twin Otter research aircraft (which we instrumented with turbulence instrumentation for a previous ONR project, the Japan/East Sea experiment) was used to measure air-sea fluxes and boundary-layer structure during RED, CARMA I, II, & III in the summers of 2001, 2002, 2004 and 2005 respectively. Since the primary focus of CARMA was on the interactions between aerosols and clouds, many flux runs were also made in and at top of the stratocumulus cloud layer to quantify vertical transport in and near clouds. The high-rate data of the vertical wind component and the fast responding temperature and humidity sensors are instrumental for detecting and characterizing the entrainment and detrainment in the vicinity of the cloud top.

For the summer 2003 CBLAST-Low experiment, we instrumented the CIRPAS Pelican aircraft (a modified Cessna 337 with only the pusher engine) with turbulence instrumentation similar to that we developed on the Twin Otter. We collaborate with Haf Jonsson of NPS/CIRPAS on all of these projects and Dean Hegg on the CARMA studies.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Marine Boundary-Layer and Air-Sea Interaction**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, Irvine,Department of Mechanical and Aerospace Engineering,Irvine,CA,92697-3975**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

CBLAST-Low: Data from all 19 flights underwent careful quality check, recalibration and reprocessing. They were disseminated to the CBLAST-Low community via this URL: URL:http://wave.eng.uci.edu/files/cblast/flights/.

CARMA: We conducted a very productive third observation campaign (CARMA III) off Monterey Bay in August 2005. Flight patterns were tailored to mission objectives witch ranged from high winds far offshore to aerosol gradient to rift formation. The 2-D tracks from all 17 flights are shown in Fig. 1.

Except for two flights (18th and 19th of August), when the pressure line for the angle of attack was saturated with water due flying in very "productive" clouds on previous flights, the UCI turbulence instrumentation and data system performed well. The newer integrated GPS/INS system, C-MIGITS III, with its 12-channel (compared to the 5 channels of its C-MIGITS II predecessor) has a superior performance and not GPS dropouts were experienced.

The data set was reprocessed recently due to the signal of the Rosemount fast temperature used as a reference having its power density spectrum becoming noisy above 1-Hz as revealed by spectral analysis. We used instead the data from a redundant sensor co-located on the nose of the aircraft. Another problem that was noticed and corrected is the calibration coefficients used for the infrared SST sensor were incorrect for the first half of the mission. This problem was corrected and no data were lost. We also performed our first turbulence analysis on all flights (this is how the temperature response problem was discovered) and some of the flux results will be shown in the next section.

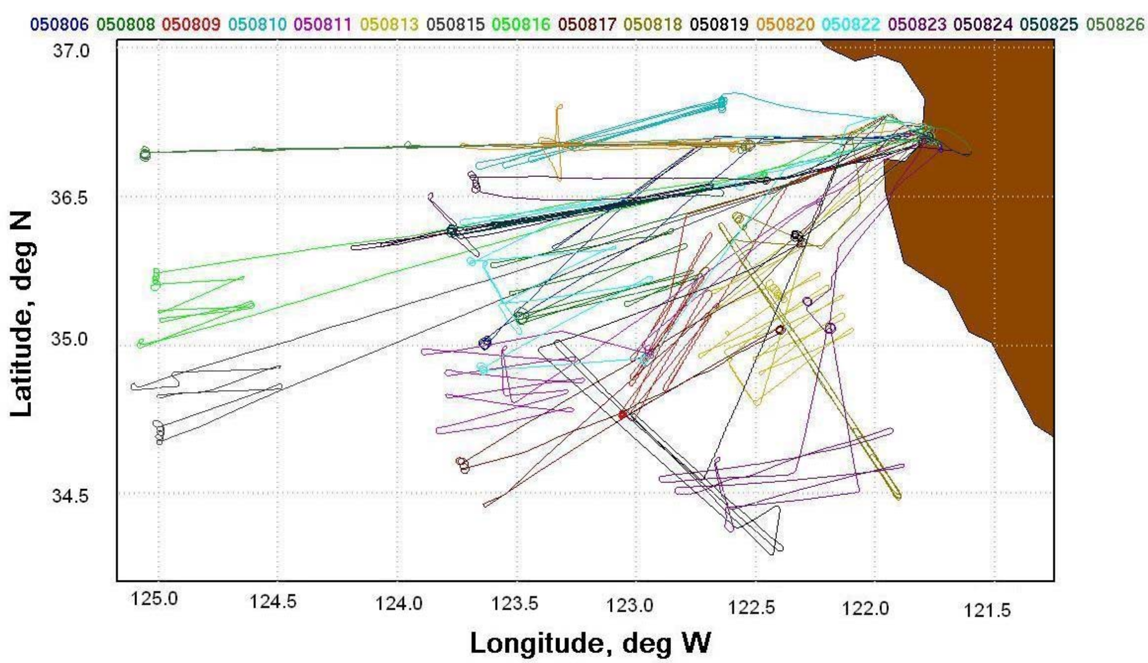

Figure 1: CARMA III tracks from all 17 research flights in August 2005

Towed Atmospheric Sampling Platform (TASP)

The Towed Atmospheric Sampling Platform (TASP) is a new and novel platform being developed for turbulent flux measurements in the surface layer of the Marine Atmospheric Boundary Layer. This project is a joint effort between the Naval Postgraduate School / Center for Interdisciplinary Remotely-Piloted Aircraft Studies (NPS/CIRPAS), Zivko Aeronautics Inc. (ZAI) and the University of California, Irvine (UCI). The TASP is cylindrical in shape of a cylinder (9" diameter and 85" long) with a hemispherical nose. It docks under the belly of its host aircraft (see Fig. 2) and can be deployed and towed at a desired elevation (as low as 10 m) above the ocean (Fig. 3).

Figure 2: The Towed Atmospheric Sampling Platform (TASP) in docked position beneath its host aircraft, the CIRPAS Twin Otter.

The TASP payload is very similar to the turbulence and meteorological instrumentation we have developed for the CIRPAS Twin Otter. It will provide measurements of the 3 components of the wind from the radome system, fast- and slow-response humidity, pressure, elevation, IR SST, velocities, attitude angles as well as other navigation data of the TASP. The main motivation to develop the TASP is to augment the capabilities of aircraft as a research tool for sampling the atmospheric boundary layer. Namely:

1. The minimum altitude at which a research aircraft can fly over the ocean is 100 feet (roughly 30 m) may be in many instances above the surface layer. The TASP will make it possible to obtain airborne measurements inside the surface layer and perhaps as low as 33 feet (roughly 10 m) which is considered the standard height for surface turbulent flux measurements.

2. Simultaneous turbulence measurement from two separate levels (aircraft and TASP) should improve statistics in estimating surface fluxes and especially in evaluating flux and flux divergence. Also, simultaneous in-clouds and below or above clouds measurements will be very useful for cloud processing studies experiments such as CARMA.

3. When the TASP is deployed, for the same amount of flight time, about twice the amount of turbulence data will be obtained.

4. In case of fog or haze, the TASP will provide turbulence data below the 300 feet (roughly 91 m) minimum allowed flight altitude.

5. In case of any research instrument failure on the aircraft, the data from the counterpart instrument on the TASP would prove to be very valuable as a redundant measurement.

Figure 3: The TASP during a test flight off Monterey, CA. (Notice the steel cable tow line.)

We are currently developing the data system software that runs on a very small, low-power consumption, light-weight and rugged controller (National Instruments cRIO). We have specified all required instrumentation including the cRIO and it has been integrated on the platform. In preparation for the instrumented test flights scheduled for November 2006, we have almost completed the pre-flights calibrations.

RESULTS

Results from our analysis of the flux runs flown at the nominal 33 m ASL (100') in CARMA III are presented below. The kinematic sensible heat flux, Q_o as determined by the eddy correlation method from 250-second segments from straight and level runs are shown as a scatter plot of versus the kinematic bulk sensible heat flux in Fig. 4. The "expected" linear relationship is observed although the least-squares fitted line does not go through the origin. Due to the relatively low winds and small but positive sea-air temperature difference, the values of Q_o were low and from the ocean to the atmosphere. The relatively large scatter is due to the low values of the flux.

For comparison purposes, results from a NSF funded project GOTEX off the Gulf of Tehuentepec in strong gap out flow winds are shown in Fig. 5. Both fitted linear firs resulted in a positive intercept and slopes of comparable values.

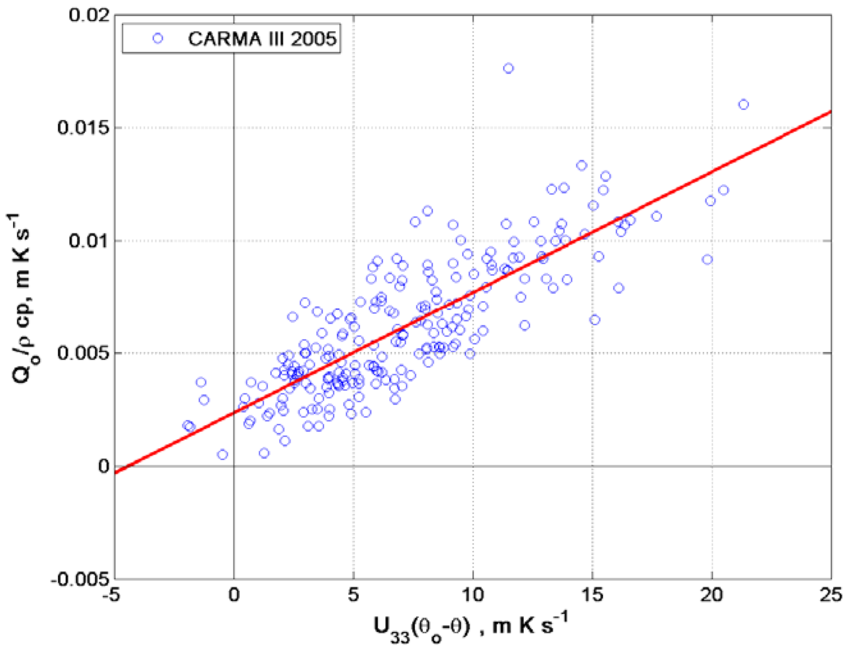

Figure 4: Scatter plot of CARMA III bulk (abscissa) versus eddy correlation (ordinate) air-sea kinematic sensible heat fluxes. The red line is the least-square fit of the data with a slope of 0.5 x 10^{-3} and an offset of 2.4 x 10^{-3}.

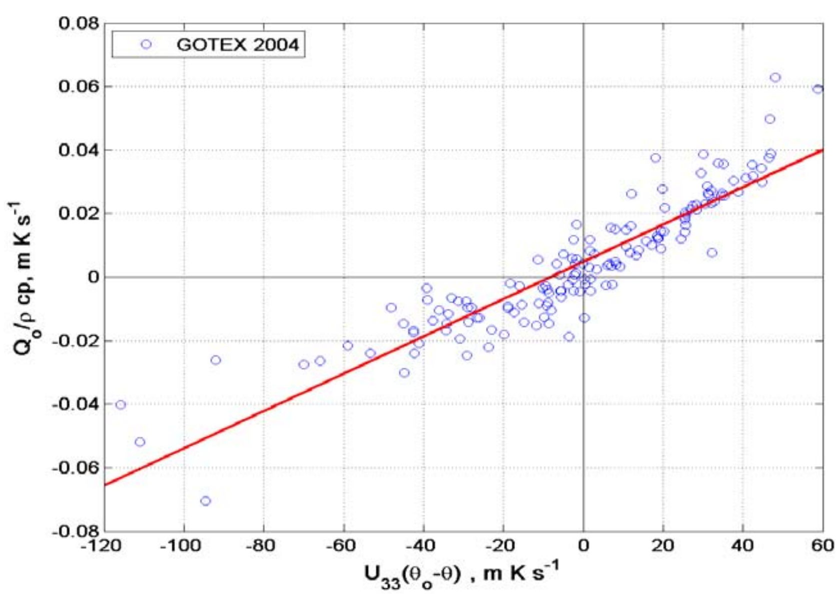

Figure 5: Scatter plot of GOTEX bulk (abscissa) versus eddy correlation (ordinate) air-sea kinematic sensible heat fluxes. The red line is the least-square fit of the data with a slope of 0.6 x 10^{-3} and an offset of 4.8 x 10^{-3}.

Variations of the kinematic momentum flux, u_*^2 (where u_* is the friction velocity), are shown in Fig. 6 (top) as a function of wind speed for all of CARMA III low level runs. Also shown are results from the Japan/East Sea (JES) ONR-sponsored experiment as well as data from GOTEX with the two latter studies having much stronger winds and more vigorous air-sea interaction. CARMA III data "fill" nicely the low to moderate winds range in the overall plot. The scatter increases with increased winds. We are exploring different statistical methods to improve turbulent fluxes estimates. Some of them involve the integral scale to be considered to estimate a flux and some involve segregation by stability and other parameters. The question is what part of the uncertainty is due to the physical process itself and what part is due to the estimation and statistical methods used. We hope our ongoing work on this question will help finding and answer to it. The drag coefficient, shown in the bottom panel of Fig. 6, exhibits a substantial degree of scatter but no clear variations with the wind speed.

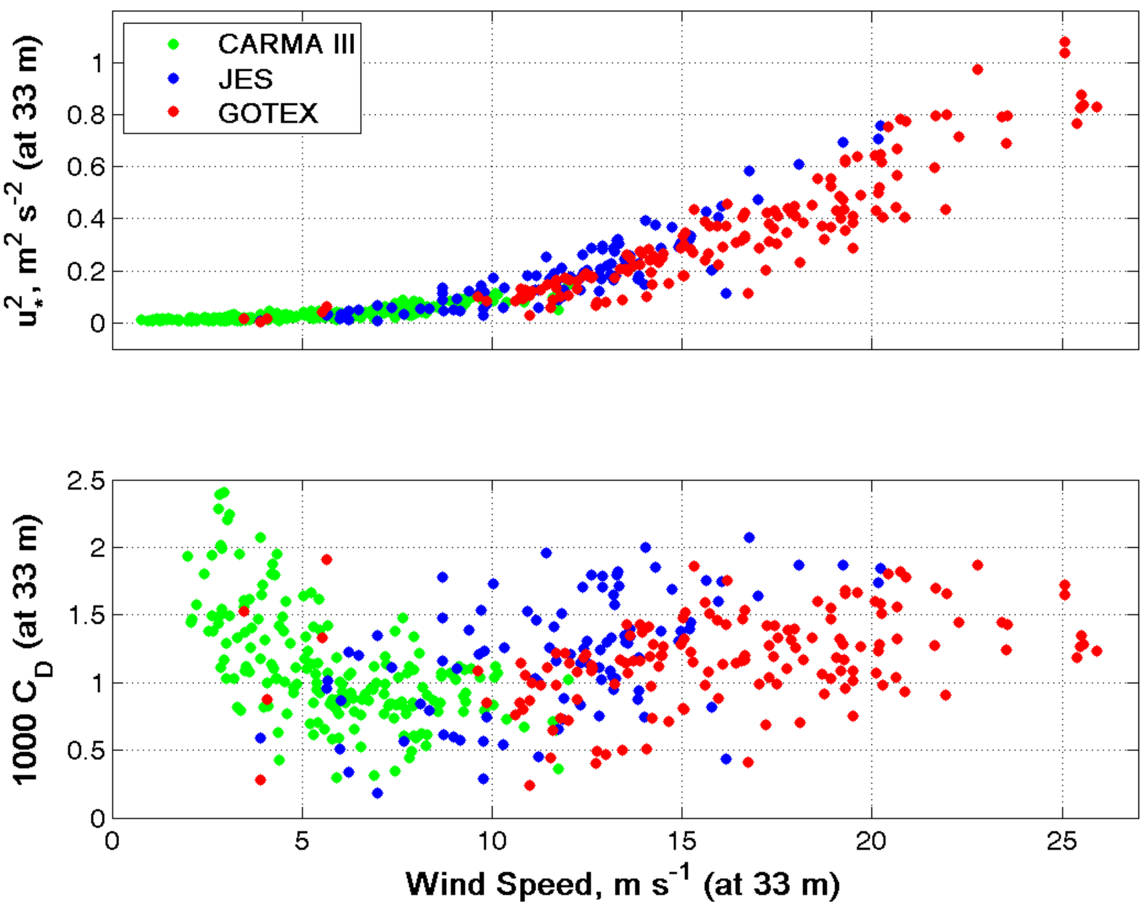

Figure 6: Variations of the kinematic air-sea momentum flux, u_*^2 (top), and drag coefficient, C_D x 10^3 (bottom) as a function of wind speed. The measurements were obtained from 460 250-s segments at an elevation of 33 m above the ocean over a wide range of wind conditions and different locations. Low to moderate winds prevailed in CARMA III (green) off Monterey in August 2005 contrasting with the stronger winds and more vigorous momentum flux observed in the gap outflow experiments during JES (blue) off Vladivostok in February 2000 and GOTEX (red) off the Gulf of Tehuentepec in February 2004.

IMPACT/APPLICATIONS

The combination of aircraft state of the art aerosol and turbulence instruments in CARMA-I and II and III is giving us new insight in the role of cloud processing on aerosol light-scattering efficiency. The combination of air-sea interaction data sets from several experiments will provide a wider range of meteorological conditions especially with respect of wind speed and stability. This will allow us to test different parameterizations of the air-sea exchanges.

TRANSITIONS

The CIRPAS Pelican aircraft has a new capability with the turbulence instrumentation package we installed for CBLAST-Low. The operation of this single engine, single pilot aircraft is significantly more cost effective compared to a lager aircraft and still it can fly for over 5 hours on a research flight.

The LI-COR 7500 fast humidity sensor is proving to be a good candidate to replace the obsolete Lyman alphas. We hope to work in the near future on the design of a special housing that will prevent its windows from getting wet when probing through clouds or precipitation.

CIRPAS has been using our calibration equations for the Twin Otter radome system. We expect CIRPAS to do the same once we determine the equations for the new radome system.

The TASP performed well during its first test flights back in the spring of 2006. We will test it in November 2006, this time with the research payload operating. If the tests are successful, the TASP will significantly increase the capabilities of the CIRPAS Twin Otter.

RELATED PROJECT

The summer 2001 data from the CIRPAS Twin Otter are part of Rough Evaporation Duct (RED) experiment (http://sunspot.spawar.navy.mil/red/). The summer 2003 Pelican data are part of CBLAST-Low (http://www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html).

We are involved in the Gulf Of Tehuantepec Experiment (GOTEX) where we used the NCAR C130 to study the air-sea interaction under strong gap winds conditions. We are in the process of comparing our findings from our ONR-funded JES cold air outbreaks experiment to those of GOTEX. The URL for GOTEX is http://raf.atd.ucar.edu/Projects/GOTEX/docsum.html)

PUBLICATIONS

Journal Articles:

Burns, S.P., **D. Khelif**, C.A. Friehe, A.G. Williams, P. Hignett, A.L.M. Grant, J.M. Hacker, D.P. Rogers, E.F. Bradley, R.A. Weller, M.F. Cronin, S.P. Anderson, C.W. Fairall, and C.A. Paulson, 1999: Comparisons of aircraft, ship, and buoy meteorological measurements from TOGA COARE. J. Geophys. Res., 104, 30,853-30,883.

Burns, S.P., **D. Khelif**, C.A. Friehe, P. Hignett, A.G. Williams, A.L.M. Grant, J.M. Hacker, D.E. Hagan, Y.L. Serra, D.P. Rogers, E.F. Bradley, R.A. Weller, C.W. Fairall, S.P. Anderson, and C.A.

Paulson, 2000: Comparisons of aircraft, ship, and buoy radiation and SST measurements from TOGA COARE. J. Geophys. Res., 105, 15,627-15,652.

Hegg, D.A., D.S. Covert, H. Jonsson, **D. Khelif** and C.A. Friehe, 2003: Observations of the impact of cloud processing on aerosol light-scattering efficiency. Tellus. 56B, 285-293.

K. Anderson, B. Brooks, P. Caffrey, A. Clarke, L. Cohen, K. Crahan, K. Davidson, A. De Jong, G. De Leeuw, D. Dion, S. Doss-Hammel, P. Frederickson, C. Friehe, T. Hristov, **D. Khelif**, M. Moerman, J. S. Reid, S. Reising, M. Smith, E. Terrill, and D. Tsintikidis, 2004: The RED Experiment: An assessment of boundary layer effects in a trade winds regime on microwave and infrared propagation over the sea. *Bull. Amer. Meteor. Soc.*, **85,** 1355-1365.

Crahan, K.K., D.A. Hegg, D.S. Covert, H. Jonsson, **D. Khelif** and J.S. Reid, 2004: Speciation of Organic Aerosols in the Sub-tropical Mid-Pacific and their Relationship to Light Scattering. *J. Atmos. Sci.,* **61** (21), 2544-2558.

Khelif, D., C. A. Friehe, H. Jonsson, Q. Wang, and J. Kalogiros, 2005: Wintertime boundary-layer structure and Air-Sea Interaction over the Japan/East Sea. *Deep Sea Research II*, 52, 1525-1546.

Dorman, C. E., C. A. Friehe, **D. Khelif**, A. Scotti, J.B. Edson, R.C. Beardsley and R. Limeburner 2006: Winter Atmospheric Conditions over the Japan Sea: the Structure and Impact of Severe Cold-Air Outbreaks. Accepted for publication by Oceanography.

Edson, JB …. **D. Khelif** et al. 2006: The Coupled Boundary Layers and Air-Sea Transfer Experiment in Low Winds (CBLAST-LOW). Accepted for publication by BAMS.

Abstracts and Conference Papers:

Khelif, D. and C. A. Friehe, 2000: Surface forcing and boundary-layer structure over the Japan/East Sea during winter cold-air outbreaks. Fall Meeting of American Geophysical Union, San Francisco, 15-19 December.

Wang, Q., H. Zuo, J. Kalogiros, C. Friehe, **D. Khelif** and H. Jonsson, 2000: Evaluation of surface flux and boundary layer parameterizations in COAMPS using JES aircraft measurements. Fall Meeting 2000, American Geophysical Union, San Francisco, 15-19 December.

Whisenhant, M.K., Q. Wang, S. Wang, J.D. Doyle, **D. Khelif** and C.A. Friehe, 2001: Grid resolution and surface flux and boundary layer parameterizations in high-resolution mesoscale models. Ninth Conference on Mesoscale Processes, Fort Lauderdale, FL, July 30 - August 2, 2001

Khelif, D. and C. A. Friehe: 2001: Air-sea fluxes and boundary-layer structure over the Japan/East Sea during winter cold-air outbreaks. The Oceanography Society Biennial Scientific Meeting, Miami Beach, 2-6 April.

Khelif D. and C.A. Friehe, 2003: Marine atmospheric boundary-layer structure and air-sea fluxes under moderate trade winds regime. Preprints,12th Conference on Interactions of the Sea and Atmosphere, Long Beach, American Meteor.

Sun J., S.P. Burns, L. Mahrt, D. Vickers, **D. Khelif** and H. Jonsson, 2004: Characteristics of air-sea interaction in surface and wave layers during CBLAST-Low.16th Symposium on Boundary Layers and Turbulence, Portland, ME, American Meteor. Soc.

Khelif, D., H. Jonsson and C.A. Friehe, 2004: Meteorological and turbulence measurements from aircraft during CBLAST-Low. Ocean Science Meeting, Portland, OR, 26-30 January.

Khelif D., C.A. Friehe and H. Jonsson, 2004: Marine atmospheric boundary-layer structure and air-sea fluxes during CBLAST-Low. 16th Symposium on Boundary Layers and Turbulence, Portland, ME, American Meteor. Soc.

Khelif, D. and C.A. Friehe, 2004: Aircraft measurements of boundary-layer structure and air-sea fluxes over the Japan/East Sea during winter cold-air outbreaks. 4th Annual EMS Meeting, Nice, France, 26-30 September.

Friehe, C.A, **Khelif, D**., W. K. Melville, Shouping Wang, Qing Wang, 2005: Atmospheric boundary-layer measurements in the Gulf of Tehuantepec. TOS, Ocean Research Conference, Paris, France, 6-9 June.

Melville, W. K., Kleiss, J., Romero, L., Friehe, C. A., **Khelif, D**., 2005: Winds, surface waves and upwelling in the Gulf of Tehuantepec Experiment (GOTEX). Dynamic Planet, Cairns Australia, 22-26 August.